CAPACITY BUILDING FOR A RESPONSIBLE MINERALS TRADE

INCREASING GOLD RECOVERY WHILE REDUCING ENVIRONMENTAL HARM

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COVER PHOTO: Testing the Z sluice in Nyamorhale Mine. Credit: Paul Cordy.

CAPACITY BUILDING FOR A RESPONSIBLE MINERALS TRADE (CBRMT)

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EXECUTIVE SUMMARY

The purpose of the mission described herein was to introduce more efficient gold recovery methods, train miners and project staff to build and operate gold concentration equipment, and assess possible solutions for improving environmental stewardship. To this end, CBRMT's subcontractor, Cordy Geosciences, built and tested several gold concentration methods at the Nyamurahle pilot site with various ore samples and water supply methods. The sluice tests were particularly successful, and dozens of miners attended the demonstrations each day to see how a different system would impact their gold recovery methods. Ore waste that was processed twice (reprocessed waste ore, or "tailings") yielded gold in amounts far exceeding the expectations of miners. In one case, the new Z-sluice recovered more than 2 grams per ton (g/T) from tailings.

Current gold ore-processing methods are wasteful. Significant amounts of material are lost due to overgrinding, lack of size control, careless crushing, non-uniform grinding, or impatient operators. However, reprocessing tailings with the same inefficient methods is worthwhile for these miners despite the time required. Inefficient as the current system is in terms of labor, it also distributes wealth to lower socioeconomic ranks; ore re-processors often do not have access to primary ore and thus have lower incomes. If that same amount of labor were applied to more efficient processing of the ore the first time, the overall efficiency would be increased and more ore could be processed for greater profit. Ultimately, the labor applied to processing primary ore is inefficient because processors are paid by the sack and have no direct incentive to work more carefully and judiciously. Best practices often require more diligence and effort and/or skill to operate, so operators should be allowed to benefit from the results generated by these new processes The best way to solve these problems would be for the cooperative to process all of the ore in bulk and pay miners and ore processors a base salary plus a percentage of profits as a performance incentive. If the cooperative had greater control over the gold trade on site—for example, if the cooperative incorporated the role of the negociant (gold buyer) and retained the middleman profits—the cooperative could leverage the extra income to provide and maintain better tools. New tools and methods will require equal or greater labor to operate, thereby maintaining employment while increasing processing capacity and improving gold recovery efficiency.

Mercury is not currently being used at Nyamurhale, which is largely due to the patience and skill of the negociant. This negociant's ability to tease out the gold grains from the tiny portions of shovel pan concentrate is remarkable and precludes the need for miners to use mercury amalgamation to consolidate the gold into a nugget that can be easily evaluated and weighed. Nevertheless, mercury could be introduced at any time, and it would likely be easier, faster, and equally effective compared with current methods. The best way to ensure that mercury is never used is to introduce best practice grinding, concentration, and quality control systems that can demonstrably recover more gold than amalgamation at a reasonable cost in terms of capital and labor.

Observing the protocols described in this report, combined with diligent record keeping, can produce long-term average ore grades and production efficiency upon which to build stable and reliable planning, production, and management. These protocols would also serve the goals of transparency and due diligence by building robust time series of ore extraction and gold production to compare gold yields.

ORE-PROCESSING RECOMMENDATIONS:

The recommendations here include a list of equipment options and techniques that could improve gold processing efficiency by mechanization or manual power. Either way, the basic goals remain size classification, optimal grinding, careful concentration, and direct smelting. The report recommends two changes: mechanized and non-mechanized. Both approaches use the same quality control protocols, and both should be implementable with the resources available in Bukavu or Kigali.

The non-mechanized approach:

- Hand-crank trommel
- Mortar and pestle or hand crank ball/river stone mill
- Manual shaker screen
- Barrel collectors
- Z sluice

The mechanized approach:

- Motorized trommel
- Water pumps and hoses
- Mechanically driven ball/river stone mill (ideally with a mechanical crusher feeding it)
- Z sluice
- Shaker table
- Generator

Mechanization is not necessary to improve all aspects of ore processing. However, best practices require more effort and may be more likely to be adopted if there is a labor-saving element to them. In practical terms, procuring ready-fabricated ore processing equipment in the Democratic Republic of the Congo (DRC) may be challenging but is not impossible. The report also focuses on equipment that can be built by local carpenters and welders out of readily available materials in Bukavu, and offers some recommendations for buying equipment from locations abroad.

More efficient and more mechanized ore processing could expand the amount of ore that is economically viable. At present, the miners only process ore that is very high grade, judging lower-grade material as not being worth the effort to process. Processing more of the ore extracted could greatly increase overall site income. It would also be greatly beneficial to have the cooperative buy the raw gold, smelt it into ingots, and have the ingots analyzed periodically to assess variability.

With prior preparation and purchasing, an ore grinding optimization experiment could be done on site using only a cement mixer, roughly spherical river stones, wooden sluices, a small generator, some metal window screening mesh on wooden frames, and an abundance of ore and labor. A long-term (days or weeks) test of a complete best practice processing circuit (which includes crushing, grinding, concentration, and smelting) in parallel with the traditional method to measure all inputs and gold production to demonstrate techniques and establish a business case for best practices. Many individual recommendations for improving efficiency would only improve recovery by a few percent. When various parts of the processing chain are improved, small changes can accumulate to overall increases in production of 15 or 30 percent. It is for this reason that it is important to address all aspects of efficiency at once and test a fully optimal system against the traditional method.

IMMEDIATE ORE-PROCESSING RECOMMENDATIONS:

1. Contract a welder to build sledgehammer mortar and pestle systems.

2. Buy a hand pump to feed the sluice flow regulator and rocker screen without using buckets.
3. Set up a shaker screen, water pump with hose and spray nozzle, and a collector tarp to wet screen raw ore, then sluice the portion that passes the screen and crush/grind the rest.
4. Permanently set up the Z sluice in an existing washing station with a hand pump.
5. Build a hand-crank trommel and other tools described in this report.

ANALYTICAL RECOMMENDATIONS

A multi-element analysis of ore from the site would highlight potential geogenic chemical hazards inherent to the ore such as copper, arsenic, and lead. CBRMT could also sample and analyze each primary ore type (greenstone, quartz veins, or saprolite, but not alluvial) to ascertain the variability of gold purity. These analysis are however costly and CBRMT would need to determine the cost/benefit of such analyses.

ANALYTICAL RECOMMENDATIONS:

1. Verify and organize the existing production data to estimate yield. For example, divide the monthly gold production by the total average monthly site ore production to determine the yield in grams per ton (g/T). Build an economic model of the site.
2. Analyze typical raw ore samples and to measure typical sack weights and per-sack gold yields to improve precision of the above site production and yield data.
3. Use average site ore production data and lab analysis results, determine what the site's total revenues could be if best practices were used, and compare that with present gold production estimates based on present yield.
4. Based on forecasted revenues, build a cooperative reorganization plan to capture as much of production under better methods and fund the operations of a crush-grind-concentrate circuit.

EXPLORATION RECOMMENDATIONS

It is recommended that expert miners be hired to carry out exploration under the guidance of an exploration geologist to take samples for lab analysis. Exploration would include choosing sampling strategies and locations, conducting direct pit and trench sampling, and monitoring and recording artisanal field assays (such as crushing and panning small samples in a shovel).

It may be useful to trench and sample beyond the existing mine in a direction perpendicular to the orientation of the gold veins. This could uncover richer veins and extend the life of the mine. This approach could also be used to assess other mining methods that might be safer or more efficient, such as open pit or terrace mining.

RECOMMENDATIONS FOR A TURNKEY MECHANIZED SYSTEM

An imported turnkey approach could be useful; however, this approach will be costly in capital and operational terms and would legally change the site from artisanal to a "petit mine" status. Generally, processing plants cost $20,000 dollars per ton of ore processed. Therefore, at least $50,000 to $100,000 worth of equipment and installation costs would be necessary for a plant that produces 2 to 5 tons of ore per day. Employees would be needed for import duties and shipping, a generator and diesel fuel would be needed to run the plant, and a small machine maintenance shop would be needed with a stock of spare parts. Consideration should be given to APT technologies (South Africa), Mount Baker Mining and Metals (MBMM; USA), and Sepro (Canada) for such a system.

A turnkey solution would have all the basic functional elements described, as well as similar optimization and quality control protocols; the only difference would be the high quality of manufactured equipment and analytical tools. The plant would have one or two crushers (jaw crushers are easiest), a grinding mill (such as a ball mill), and either a shaker table or centrifuge. Providers of these services may try to include a continuous feed system, but this could lead to significant gold loss if the feed rate and consistency are not maintained. A batch mill is easier to optimize for different ores, as it is possible to adjust milling time to obtain the right grind size, and the mill can be sampled to monitor this. The shaker table and centrifuge are the best readily available tools to concentrate gold, but the centrifuge represents a significant upgrade in terms of technical capability for operation and maintenance. MBMM currently distributes a shaker table, and unlike cheaper Chinese products, it can compete quite well with a centrifuge in terms of recovery. If a Chinese supplier is chosen because of costs, the Artisanal Gold Council should be contacted. They have successfully implemented efficient and intuitive ore-processing plants in Africa using Chinese equipment, and have reliable sources of quality equipment in China.

The possibility of using solar electricity to power mineral processing machines was also discussed. Crushers, ball mills, and centrifuges need more power and current to operate than feasible with solar power. Even shaker tables and water pumps require ½ hp motors that each require 800Ah of battery supply and six large solar panels. Generators are more practical if mechanization is the goal.

1.0 INTRODUCTION AND BACKGROUND

The USAID-funded Capacity Building for Responsible Minerals Trade (CBRMT) project goal is to strengthen the capacity of the Democratic Republic of the Congo's (DRC) and regional institutions to regulate and control a critical mass of the strategic mineral trade in eastern DRC, and to help transparently transform the region's mineral wealth into economic growth and development. Tetra Tech contractor, Cordy Geosciences, analyzed and suggested improvements for artisanal mining and mineral processing techniques at Nyamurhale Mine, in South Kivu, DRC, as part of the CBRMT Gold Pilot Project.

The purpose of the assignment was to provide basic geological, technological, and environmental assessments of existing artisanal and small-scale mining production, assist in basic training on efficiency options using equipment procured by CBRMT, and provide suggestions for future improvements.

1.1 NYAMURHALE MINE AND PROCESSING SITES

Approximately 300 miners currently work at the Nyamurhale Mine site. They have been mining there since 2002 when the Congolese army pushed the Mai Mai rebels out of the area. The Mai Mai first found the gold deposits in the area's surface gravel, but it is unknown how long they had mined the area before being evicted or how much gold they pulled out of the ground. Nevertheless, a large area appears to be undeveloped.

Figure 1: View of mines from the village

The present operation includes approximately 100 active holes up to 30 meters deep, although most are considerably shallower. The miners do not dig deeper because they are likely to hit the water table. About 40 holes are inactive, most of which are filled in with barren earth to prevent infiltration of water that could compromise the stability of other holes.

Figure 2: Views from the mine site

Exploration at the site is haphazard, new holes are dug near existing ones. Miners estimate that 20 to 30 percent of new excavations encounter gold. Miners only exploit the weathered saprolite sand and gravel, leaving the larger chunks of quartz and rock in waste piles. The miners understand that this harder material contains gold, and they use the presence of quartz as a positive indication of their excavations' gold potential. Although this hard material likely has value, miners currently have no crusher or mill to process it.

Figure 3: Shallow Nyamurhale Mine pit

Figure 4: Saprolite with clearly visible weather-resistant quartz crystals

Note: Miners consider this waste rock because they do not have a mill to grind it. However, it is the same material as the processed sand.

Because no water is present at the mine site, miners bring their buckets to the village water source, a 10-minute walk downhill. A USAID artesian well was built to provide clean drinking water for the community, and the miners use it profligately to sluice their gold. Miners carry the ore in standard rice sacks; the ore itself usually weighs more than 50 kilograms. Miners claim that each sack contains between 2 and 10 grams of gold. This primary material is hand crushed by hammering a hand-sized rock against a larger rock. There is no size control apart from visual judgement of the person doing the crushing, and chips of gold-bearing quartz often fly away to the side and are lost. The crushed ore is ground further, using mortar and pestle with a hand-sized rock that the miners slide back and forth against a larger flat rock. This ground ore is then fed to a "*loutra*", or sluice.

The loutra method of sluicing often loses significant quantities of fine gold. Loutras are made by hammering corrugated metal sheets flat and then folding them into a semicircular curve. Miners block the downstream end with balled-up cloth and place the ore upstream. As water washes down the sluice, the miners rub their hands in the ore, pushing it up against the current. The lighter grains pour out around the edges of the cloth into the waste pool below (basically a large hole dug into the ground). The miners then take the cloth away and wash the concentrate into a shovel, which they then wash further to obtain the gold. No mercury is used in this process; however, some fine gold likely flows out with the waste. The waste is shoveled out of the waste pool and stacked in adjacent piles to be further processed, sometimes by regrinding and sometimes by rinsing on a banana bark-lined sluice.

Figure 5: Loutra method

Note: Only coarse gold is recovered in this process. However, rich ore contains much coarse gold, so the processes are profitable in spite of significant losses.

1.2 GEOLOGY AND MINERALOGY

To field test best practices for this report, the team used primarily rusty oxidized saprolite ores. Up to four different types of ore can be processed, according to the CBRMT baseline. The geological analysis that follows is based on the limited amount of material observed in the field for this mission and brief non-technical descriptions of other ore types given in the CBRMT document: "*Rapport d'étude de base pour la mise en place de la chaine d'approvisionnement de Nyamurhale*."

Greenstone (named for the green minerals that give it a distinctive hue) consists of ancient bedrock that underlays much of the world's great gold belts. It is the highly metamorphosed agglomeration of oceanic island arc chain rocks, including volcanogenic massive sulphide deposits that formed the core of the original Pangea supercontinent. Greenstone is the parent material from which silica and metals were leached and mobilized in subsequent hydrothermal activity that re-deposited and concentrated in the form of narrow quartz veins. These veins were then sheared apart in more recent tectonic and volcanic upheavals, of which the latter process could have formed more quartz veins. Saprolites are near-surface deposits that originated as more recent volcanic rocks. Original minerals such as feldspars and pyrites have been weathered, oxidized, and leached by organic and silicic acids generated by surficial tropical and biological processes, leaving clays, iron oxides, and quartz (the latter being chemically stable in surface pressures and temperatures and therefore does not weather). Alluvial ores are river deposits resulting from erosion and transport of ancient rocks that were broken down by chemical and physical weathering. Rivers winnow out the lighter elements, such as quartz and clay, thereby concentrating the gold, magnetite, and other resistant heavy minerals, while oxidation leaches out impurities and physical wear gives the gold grains a rounded shape.

Due to the various mineralogical origins of each type of ore, different gold purities would be expected; however, within these groups, the purity should be similar considering the small area being mined. The CBRMT project field staff and the exporter (Fair Congo) report an average purity of 76 percent from Nyamurhale. Separating the gold from different source ores should be performed carefully to get enough of each to assess the purity and to determine whether there is, in fact, variability and of what magnitude. This can be done by separately analyzing each ore type. The analysis would be useful for subsequent negotiation on the sale price of the gold to those that export, as they may take advantage of the uncertainty in purity to bargain a lower purchasing price at the miners' expense. It has been mentioned that, at this site, gold is mixed with materials from other sites with higher purity gold to bolster the price paid upon export. Ultimately, this is based on faulty logic as each ingot of gold will have uniform purity, no matter the size or combinations of original ore, since the purity is homogenized during melting. The recommendations of this report explain some options for evaluating and monitoring purity.

Alluvial and saprolite ores require the least amount of processing because chemical and physical weathering have already largely liberated the gold from the host rock. Saprolites must still be milled to liberate some fraction of the gold. Nevertheless, saprolites will have a significant component of sandy matrix containing free gold nuggets and dust, which should be separated before milling the liberated gold is not ground. Over-grinding gold can make it finer and more laminar, both of which greatly reduce their propensity to settle with the heavier fraction during concentration, and instead may float away with the sterile sands and fine suspended clays. The same can likely be said of the quartz vein ores, because they are heavily sheared and discontinuous, and mixed in with saprolitic material. Finally, the greenstone material will likely be the hardest and most sulphide (as opposed to oxide) rich, and will require greater grinding action to liberate the gold. The fact that each ore is treated with the same processing approach suggests that there are marked inefficiencies in ore processing that could, in some cases, over-grind liberated gold and in other cases, leave significant gold trapped in quartz and sulphide minerals.

Potential exploration and exploitation challenges exist. For example, the sheared nature of the quartz veins might make it hard to follow the veins along the strike and discover new prospects. Saprolitic deposits are weak and subject to collapse if mine shafts and adits are poorly buttressed. By contrast, greenstone can be very hard, making it difficult to excavate. Greenstone excavation may require the miners to use explosives, despite them being difficult to legally obtain in a conflict zone. The ore is also likely to be more resistant to milling. Because ore processing laborers are paid by the sack, they are unlikely to modify their behavior to optimally process each ore type.

1.3 ORE PROCESSING DEFICIENCIES

LACK OF SIZE CONTROL

Primary material contains significant amounts of clay, mud, and sand, and should be washed prior to crushing and grinding. Clays trap fine gold and cause it to flow out with the suspended sediments. Also, much of the mined material arrives at the processing site as sand, which is of optimal size for concentration. Failing to separate this material causes it to be over-ground to a size that may float away with the wash water into the tailings, or may travel downstream in the fine suspended clays. Miners do not use detergent in the concentration water, causing the oily coating on smaller gold particles and more laminar gold particles to float, leading to gold loss.

CARELESS CRUSHING

Smashing ore by hand with rocks causes chips of ore to fly off sideways, leading to significant loss of gold ore over time. Grinding ore, using rock mortar and pestles, grinds most of the material too fine, which generates loss because small, flattened gold particles tend to float, and it also leaves a significant portion of ore in chunks that are several millimeters in diameter. Therefore, a significant portion of the remaining gold is lost.

Figure 6: Hand crushing ore

After hand crushing the ore by smashing it with a rock, the ore is ground in sliding mortar and pestle grinders.

NON-UNIFORM GRINDING

Material is currently discharged to a tarp with holes in it, which leads to further loss of primary material. Grain size control is absent during both the crushing and grinding steps, thus oversized material that should be further crushed and ground is instead washed and discarded with the waste. As well, material that is already the appropriate size is further ground in subsequent steps instead of being separated for concentration. This means that gold that is already liberated from the ore is ground too fine and flattened; fine, flaky gold has a relatively large, oily surface area that causes it to float, and then cannot be captured by most concentration techniques. This makes regrinding of tailings labor-intensive because all of the material is reground instead of only material that is too large.

IMPATIENT OPERATORS

Ore processors are often too impatient and careless to grind and sort their material properly because they are paid by the sack and have no stake in the amount of gold obtained. They want to process it as quickly as possible so that they can concentrate and obtain some gold, without sufficient attention to the resulting losses in unliberated or over-ground gold.

CARELESS CONCENTRATION

The primary methods of gold concentration use the loutra and the banana bark sluice. The loutra is actually an efficient method of separating the coarser gold fractions. This method could be improved upon by using V-shaped loutra troughs instead of semicircular ones. A V-shape would trap the heavier minerals in the bottom of the trough, thereby leading to better concentration. Nevertheless, the loutra method likely loses significant amounts of fine gold. Loutra tailings are often reprocessed in a sluice lined with banana bark, with a water box to mix the ore and water to form a slurry that flows through 1-centimeter (cm) holes in the box and onto the sluice. Sluices may be too steep to efficiently concentrate fine gold, and the water flow rates and distribution across the sluice deck too uneven to maximize gold concentration. All of the suggestions for improvement above would not likely demonstrate their inefficiency relative to original methods without processing a large uniform source material. This is due, in part, to the incremental differences expected from these methods (which would only bear noticeable fruit after processing large amounts of material) and also due to the high variability in gold content among different ore sacks being processed. Even if each bag is taken from the same puit; gold amounts can vary significantly in a given material, and also the "nugget" effect (a few large nuggets can vastly change the analyzed ore grade) could overwhelm the recovery improvements that would result from better concentration practices.

1.4 PRINCIPAL ACTORS AND BENEFICIARIES

MINERS

Mine pit production work is structured hierarchically, with the *Chefferie* as the principal governor, and beneficiary, of site activity. Muzungu is overall site manager; therefore he controls and coordinates the activities of all the actors further down the production chain in the interest of the *Chefferie*, which claims 30 percent of the mining profits. Muzungu directs the pit bosses, ensures the mine works according to the wishes of the *Chefferie*, maintains site production records and resolves disputes, if necessary. The cooperative charges each miner an annual or monthly fee for access to the mine. The pit bosses (*chefs de puit*) manage the mine pits, provide tools, and cover mining expenses. Each morning, the miners go to the pits in search of work, and the pit boss selects the miners that will descend to dig ore, bring it to the surface, and deliver it to the processing site. The *chef de puit* also splits the respective allocations between various actors in the chain of production and receives half of the total production of the pit. The *chef de puit* assigns a site supervisor (*sentinelle*) that manages the miners, oversees their activities, allocates tools and ensures their safety. He also receives a portion of the ore produced. Chief among the miners is the production manager (*conducteur de travaux*), who guides the pit excavation and ore selection. He selects his own portion of each sack of ore from the underground production as his remuneration before they are hoisted to the surface. Underground miners share roughly half of the day's ore production, minus the shares owed to the *conducteur de travaux* and *sentinelle*. Miners are not tied to a single pit, and instead move from pit to pit seeking to work in the pit that produces the greatest amount of gold in each bag of ore. Transporters are chosen from among the miners to convey the ore to the processing sites, for which the transporter is paid over 1,000 Congolese Francs by the *chef de puit* for each sack transported. Women generally do not work in the mine, although they are occasionally found in the processing centers crushing ore by hand or reworking the tailings.

The system described above for division of labor and ore production ensures that each actor in the production chain receives their share of the profits from the activities performed. It is a common method of dividing production because ore is massive and easy to divide according to the rules of the site, without workers stealing gold nuggets during the process. By contrast, to apportion profits of mining by dividing the final gold product would risk theft by those at the end of the processing chain. In the absence of trust or mechanisms to prevent theft, division of profit in the form of ore is a necessity common to African mining sites. This situation presents the most fundamental challenge to improving mineral processing methods, because ore must be processed in small batches. More efficient and more mechanized methods are generally economically viable in larger batches that reduce downtime between batches and the relative capital investment cost relative to batch size.

ORE PROCESSING LABORERS

Ore is processed by individuals who are paid on a per-sack basis to crush and grind the primary ore, or to concentrate the gold in wash plants. Miners, *conducteurs de travaux*, *sentinelles,* or *chefs de puit* with ore that needs to be processed pay those that process the ore. Finally, the socioeconomic analysis states that there are managers who purchase the gold produced from each miner's ore based on visual speculation, and then walk a short distance to the gold buyer (negociant) to sell the gold for cash.

The implication of this ore processing system is that laborers have no stake in the effectiveness of their methods, have no capacity or motivation to invest in better processing methods, and take little care in how they process the ore. The combination of the above-mentioned factors has severe negative implications when it comes to the efficiency of gold recovery. On the plus side, it leaves more gold to be recovered by people further down the socioeconomic ladder, including women. On the minus side, part of the inefficiency is increased fine gold generation (overgrinding due to poor size control and rudimentary mortar and pestle grinding), which is mostly lost in primary and subsequent processing.

NEGOCIANTS

Miners bring their shovel blade with gold over to the negociant, who lights a candle to dry out the shovel from underneath. He then brushes the gold concentrate (which has roughly the grain size of fine sand) onto a white ceramic plate, and grinds it a bit with a magnet to break it apart and pull out the magnetic minerals.

Figure 7: Drying the gold with a candle so that the negociant can sort and weigh the gold

The negociant separates out all the tiny grains of pyrite and returns those to the client along with the magnetics. He does this by painstakingly picking out individual grains of pyrite with the end of a plastic matchhead that he licks to make it stickier. A piece of foam helps the negociant brush the non-gold particles away and brush the gold into his measuring pans. He uses the matchstick to tease out individual crystals.

Figure 8: The negociant weighing gold

The negociant's hand scale is intuitive and transparent; he balances it empty to show the miner that it is not biased. The matches and coins, however, are imprecise and probably favor the negociant.

Negociants inevitably give the lowest price possible for the gold given to them, exploiting the fact that they have no idea of the gold purity nor any option to shop around for a better price. This reduces the profit that accrues to the lowest strata of the value chain, and therefore minimizes the capacity for investment in more efficient methods on the part of the *chefs de puit* and the miners themselves.

SERVICE DE MINES, AND SERVICE D'ASSISTANCE ET D' ENCADREMENT DU SMALL-SCALE MINING

The infrequent presence of institutions such as the *Service De Mines* and *Service d'Assistance et d' Encadrement du Small-Scale Mining* (SESSCAM), and the lack of useful services (apart from licensing, taxation, fees and enforcement) means that there is little incentive or pressure on miners to formalize. This, in turn, leads to less funding for the provision of services and enforcement.

COLLECTEUR DU MWAMI (TRADITIONAL AUTHORITY

The sole function of this actor is to collect a share of the ore for the traditional authority known as the Mwami. The share used to be 50 percent, which reduced the incentive for pit crews to be selective in ore production. It was not efficient or profitable for laborers to produce the highest possible grade ore when the Mwami was going to take half anyway. Pit crews produced more lower-quality ore, keeping the bags that were selectively filled for themselves. This resulted in increased labor requirements to process the ore, which generated less value, and decreased recovery efficiency due to higher proportions of clays and lighter minerals. The Mwami has agreed to eliminate this practice.

2.0 MINERAL PROCESSING METHODS

The purpose of mineral processing tests is to determine optimal ore processing methods for a given type of ore. This is important not only at the outset of plant design and construction, but also as miners process different parts of an ore body or ores from different locations. The most appropriate ore-processing method will depend on the characteristics of the ore in question. Ore and the gold within vary by region, with characteristic chemistries, grain size distributions, and artisanal mineral processing methods have evolved to extract gold from a deposit using available tools. Miners often have preconceived notions of optimal ore parameters; for example, miners in Kafia Wema believe that ore must be a very fine powder, yet in Diwali and Benguet, Philippines, miners believe that a fine but sandy texture is best. This broadly relates to the relative grain sizes of the gold in each area. Nevertheless, mineral processing tests can suggest changes in techniques to liberate more gold or reduce costs. In Diwali, milling tests showed that gold recovery could be improved by cutting milling time in half—saving time, electricity, and equipment wear.

In general, mineral processing testing is important for process control. It can reveal how much gold can be extracted from a given mass of ore and how much will be lost to the tailings. Ideally, testing will also reveal the ore grade, or concentration of gold in the ore. This can be difficult to quantify because of statistical difficulties relating to gold's tendency to form in nuggets and because gold tends to occur in very small concentrations that are difficult to measure. Mineral processing tests and an ore analysis program can produce long-term averages of ore grades and production efficiency upon which to build stable and reliable planning, production, and management. This analysis would also serve the goals of transparency and due diligence by building robust time series of ore extraction and gold production.

All ore tests measure the mass of input ore, gold recovered, and gold lost to the tailings, and these values are used to assess the yield of each method tested. For the testing process described in this report, the team paid miners for the ore used for processing and gave the miners the gold produced when finished, helping to allay their fears that new methods would recover less gold than anticipated. The final concentration method tested in each experiment was hand panning with a shovel blade, as is traditionally done. Experiments that could have replaced this technique were more time consuming and costly. Therefore, the tests focused on primary concentration, where there is greater need for improved efficiency. An expert panner should be able to recover more gold than by using another chemical-free method, although it is common to process concentrate only. It is time consuming to process bulk ore by panning. The team paid workers were paid to pan the tailings of each process to determine how much gold was lost using different methods.

Figure 9: Finishing panning with the shovel blade

2.1 DAILY ACTIVITIES

The testing in the field took place between November 8 and November 11, 2017. On Day 1, the team sieved ore to assess grain size distribution, and then used prefabricated portable aluminum sluices (by Keene) to concentrate the gold. The group sluiced all of the ore that passed the #20 (coarse sand size) mesh to determine how much was already liberated in the raw unprocessed ore. On the following day, the team trained the miners to build the Z sluice using blue-looped rubber 3M carpets purchased by the CBMRT project. The group tested the Z sluice using tailings that had been previously processed twice.

Figure 10: Miners building the Z sluice

On November 10, the group built and tested a jig on primary ore. The first batch was did not contain any gold but did contain pyrite, helping to indicate relative effectiveness of concentration. The second batch of ore contained significant gold, which the Z sluice recovered with no discernable losses in the tailings. On November 11, the team repeated the Z sluice and jig experiments to verify their efficiency.

2.2 MEASUREMENT

The team used a 100-kilogram hanging spring scale and a digital scale with a 0.1-gram resolution to weigh samples. The group measured ore in the sacks in which it was transported, also weighing the sacks on their own to subtract the extra weight. Similarly, the team weighed gold on small pieces of paper and subtracted the paper's weight from the mass of gold measured. Finally, they used a clinometer to measure the slopes of the sluice decks to ensure that they were laterally level and sloped optimally at between 10 and 15 degrees.

2.3 SIZE CLASSIFICATION WITH SIVEE TEST

Materials:

- Sieve stack (Tyler mesh 12,20,50,100)
- Scales (~100 kilograms and ~0.5 kilometer)
- Ore >10 kilograms

Purpose:

A sieve test determines the distribution of grain sizes in a sample, whether milled ore, crushed ore, tailings, or gold grains. This test is useful because optimal gold liberation usually occurs when most of the grains are milled to a certain size. If it can be determined which grain size produces the optimal gold liberation, the test can show whether the target grain size has been achieved or if the milling duration needs to be changed. Also, an analysis of the gold content in each sieved fraction can be used to assess the degree to which gold has been liberated from the ore, and consequently judge the effectiveness of milling.

Method:

SIEVE TEST PROTOCOL:

1. Thoroughly wash and dry all sieves ahead of time.
2. Stack the sieves in decreasing order of mesh size.
3. Weigh the total mass of ore to be sieved. Avoid overloading the sieves if a significant amount of 50 mesh grains is present, because hand-shaking large quantities of fine grains can be quite labor intensive. Do not sieve more than 2 kilograms of fine-powdered ore/tailings, or use the wet sieve method described below.
4. Place the ore in the top sieve and shake vigorously, making sure not to shake so hard that ore spills out from between the sieves.
5. Empty each sieve into a separate, pre-weighed container and weigh the contents.
6. Add up all the weights to find out how much material was lost/stuck to the sieves during sieving.

7. Separately pan each fine sieve fraction (<20 mesh) and visually inspect coarser fractions for gold nuggets.
8. Visually estimate the amount of gold in each sieve fraction. Testers and miners (if present) should reach a consensus as to what percentage of the total gold will be held within each panned concentrate and tailings sample.
9. Take pictures of the gold in the concentrate, using a one franc coin for scale and a piece of paper. Record the date and the test number.
10. If practical, for each sieved fraction, amalgamate the gold and measure the weight of the amalgam and sponge gold that results.
11. Enter the results into an Excel sheet or database.

WET SIEVING

If most of the ore is very fine powder, it may be difficult to separate the finest grains fully using the dry sieving approach. If this is the case, weigh the cleaned sieves before sieving, wash the ore through the sieves with water, then allow the sieve to fully dry. Finally, weigh the sieves separately and subtract each of the clean, dry sieve weights.

2.4 KEENE PORTABLE SLUICING

The team brought two portable sluices (Keene brand) to the site to enable rapid setup. Each one provided a handy, highly portable solution that demonstrated the features of a good sluice.

Portable sluices must be placed in steady and adequate streams of water. Ore is mixed into the water flow and gold concentrates in the carpets. The sluice is then dismantled and washed, and the concentrate is panned to separate the gold.

Figure 11: Curious miners investigating the prefabricated portable aluminum sluice

2.5 FLOW REGULATION

Regulating water flow onto sluice decks is important for achieving a rate at which lighter minerals are washed down the sluice while preventing surges that can dislodge gold caught in the carpets. The flow regulator is composed of a water jug with the bottom sawn off and a PVC pipe friction fit into the neck of the jug. The holes in the pipe provide the main flow regulation. Steady flow is achieved by keeping the water level above the highest hole in the regulator pipe. The open top end of the pipe prevents surges by maintaining air pressure equilibrium. The flow rate is changed by blocking upper holes with tape until reaching the desired water flow speed onto the sluice decks. Therefore, once the correct speed is achieved, the flow rate will remain the same regardless of how much water is fed into the regulator.

Figure 12: A flow regulator allowing for a steady water supply while maintaining flows

Figure 13: Bucket feeding the flow regulator directly from the tailings catchment bucket to recycle sluice water

2.6 Z SLUICING

The Z sluice optimizes chances for gold recovery by causing the ore slurry flow to slow down by changing direction on the second stage. The Z sluice is made up of several key components, which are listed below.

WATER BOX

The water box is made by inserting a wooden wall about 1 foot from the top end of the sluice box (framed with a wooden end piece to stop water flowing out the wrong end). This forms a catchment area on which the flow regulator rests and into which water discharges. Water flows into the water box until spilling over the barrier and into the slurry box. This further ensures smooth and non-turbulent (laminar) water flow and even water distribution across the sluice deck. Laminar flow and lateral distribution maximize gold concentration by avoiding channeling (which produces higher flow velocities in some parts of the sluice decks) and turbulence (which can re-suspend fine gold particles).

SLURRY BOX

The slurry box is made by installing a wooden partition across the sluice deck that is lower than the sides of the sluice deck. This holds the ore in place while it is mixed with water to create the slurry, allowing it to pour evenly onto the sluice deck, further limiting turbulence.

Figure 14: Adding the ore to the mixing trough and stirring by hand to make the slurry

Figure 15: Mixing twice-reprocessed tailings into a slurry by hand in the mixing trough just below the flow regulator discharge

Figure 16: Z sluicing

ZIG-ZAG FORMATION

Regardless of sluice method, gold is most concentrated in the first meter of sluicing as water gains too much speed after that for gold to settle. The Z shape of the Z sluice forces the water to stop at the angle and accelerate from zero velocity in the second sluice length, doubling the effective (low-velocity) concentration length of the sluice. The zig-zag design also keeps the water feed to end in line with the water discharge, making it easy to recycle waste water into the water box.

Figure 17: Z sluice ready for concentrating

SLUICE ANGLE

The slope angle of the sluice should be between 10 and 15 degrees, as higher angles are better suited to capturing coarser gold. Higher angles wash out lighter grains more quickly and allow for higher feed rates (or require less frequent cleaning of the carpets), but higher flow rates can also wash out finer gold particles. By contrast, lower angles result in lower water flow speeds, allowing fine gold to settle, but the carpets fill up with sediment more quickly (and require more frequent cleaning and a lower-grade concentrate). The choice of slope depends on the grain size distribution of the gold in the ore. A series of holes in the vertical supports of the experimental sluice allow the sluice to be bolted in various positions, enabling the user to choose the height and slope angles of both sluice decks.

Figure 18: Use of a smartphone clinometer app to level the sluice deck and set the sluice deck inclination to 15 degrees in the direction of flow

CARPETS

Carpets help catch gold and heavy minerals, while allowing lighter minerals to flow down into the tailings pond. The finer texture of the green felt Keene carpets captures finer gold particles.

Figure 19: Setting up the Z sluice

Plastic lines the sluice to stop fine gold from getting caught in the wood grain or falling through the side cracks. It also speeds up the cleanup process. Green fine-weave carpets are used that on the lower scrubber sluice.

RIFFLES

Riffles serve the dual purpose of holding the carpet down and creating eddies to help clear the light material out of the carpet and concentrate the gold. Miners usually use bamboo sticks (as in this field test) or square batons. Riffles should be made with a 45-degree angle on the upstream side to reduce turbulence and prevent buildup of ore on the upstream side (see Figure 21). Miners usually clear this buildup by running their fingers back and forth along the riffles, creating turbulence and channeling of water, leading to poorer concentration. The riffles are held in place with small pieces of rubber wedged in between the riffle ends and the sluice side-walls. The exact width of riffles is not important because sluice deck widths are not perfectly uniform.

Figure 20: Top sluice is lined with blue carpet because it catches coarse gold better

Riffles were added to the sluice to hold down the carpet and create eddies where the gold can settle out of the flow.

Figure 21: Improved riffle profile

The upstream end of the riffle is on the left.

Figure 22: Riffles installed with the beveled edges placed uphill

Bits of rubber are used to fit the riffles tightly so that they remain in place and keep the carpets fixed to the sluice deck.

PLASTIC LINER

The blue moss and green felt carpets (held down by riffles) both allow concentrate to collect underneath them. Plastic liners prevent gold from getting stuck in the crevices of the wood sluice decks, which would complicate comparisons of different sluicing trials. Liners also keep the sluice decks and water box relatively dry, helping to prevent them from rotting.

Figure 23: Lining the sluice decks with plastic

TAILINGS CATCH BASIN

As part of the test, the team added a wash basin to the end of the sluice into which the tailings could pour into. This served to stir up the tailings and wash away the fine sediments in the overflow. The principal purpose of the tailings catch basin was to assess the amount of gold being lost in the tailings.

Figure 24: Tailings catch basin

SLUICE PROTOCOL:

1. Set up the sluice as shown in the above photo, maintaining laterally level sluice decks on 10–15-degree angles and carpets held firmly in place by riffles. Make sure to have a tailings catch basin at the end of the lower sluice deck.
2. Fill the flow regulator jug with water by pouring in buckets of water lifted out of the waste pond. Keep the regulator holes fully submerged as much as possible.
3. Mix the ore into the slurry box and stir it in with fingers.
4. Stop and clean the sluice carpets when they start to get covered in sediment, or when ore is gone, whichever comes first.
5. Carefully clean out the sluice and pan the gold.

SLUICE CLEANING PROTOCOL:

1. Before cleaning the sluice carpets, exchange the tailings catch basin for a clean, empty basin.
2. Beginning with the lower deck, remove the riffles and carefully wash them in the new basin.
3. Roll the lower deck carpets from bottom to top and place them carefully in the new basin.
4. Pour water onto the top end of the lower sluice deck to wash the concentrate that is left under the carpets into the new basin.
5. Put the new wash basin aside, and replace with a third, clean, empty basin.
6. Repeat steps 1 through 4 for the upper deck carpets.

7. Clean each of the carpets in their respective basins by first unrolling them and shaking them out in the water, taking care not to spill any concentrate over the edges of the basin.
8. Pan the concentrate in each of the two concentrate basins and the tailings catch basin, and visually estimate the amount of gold. Come to a consensus among the experimenters and miners (if present) as to what percentage of the total gold is held within each panned concentrate and tailings sample.
9. Take pictures of the gold in the concentrate using a one franc coin for scale and a piece of paper indicating date and test number.
10. If practical, amalgamate the gold and measure the weight of amalgam and sponge gold that results.
11. Input the results into an Excel table or database.

2.7 JIGGING

To prevent overflow mixing of waste and concentrate during jigging, seal the edges of the sieve pan with duct tape and a skirt of plastic. This method ensures that ore can be loaded into the jig without spilling and the ore will not spill out if tipped.

Figure 25: Jigging

Materials for Jigging

- Sawhorse
- 12-mesh Tyler screen
- Large wash basins
- 2-foot by 4-foot wood pieces
- Door hinge
- Marbles
- Wire
- Eye screw (eye ring with threaded screw end to screw into wood and attach jig)

Method:

Attach the 2x4 to the sawhorse with the hinge in a see-saw-like arrangement (see figure). Drill three small equidistant holes just under the lip of the 12-mesh sieve. Thread the holes with wire and arrange the elements so that the loaded sieve rests level. Hook the wire to the end of the 2x4.

Figure 26: A 2x4 hinged to a sawhorse to make a jig

Spread the marbles evenly inside the sieve and spread the ore evenly on top, leaving at least 1 inch below the sieve's rim uncovered. Move the arm (2x4) up and down to lower the sieve into the water without pushing the ore out the top. Next, remove the sieve and collect the concentrate from the bottom of the tailings wash basin. Finally, clean the marbles and dispose of the tailings safely.

Figure 27: Children's marbles used as "ragging" material

Water forced through this material surges up and down through the marbles, sending lighter particles upward and sucking heavier particles downward.

Figure 28: The purple basin catching the concentrate and guiding the pan as it is raised and lowered

This forces the water to drain up and down through the marbles and ore.

Figure 29: Loading ore (sluice concentrate) by hand into the jig

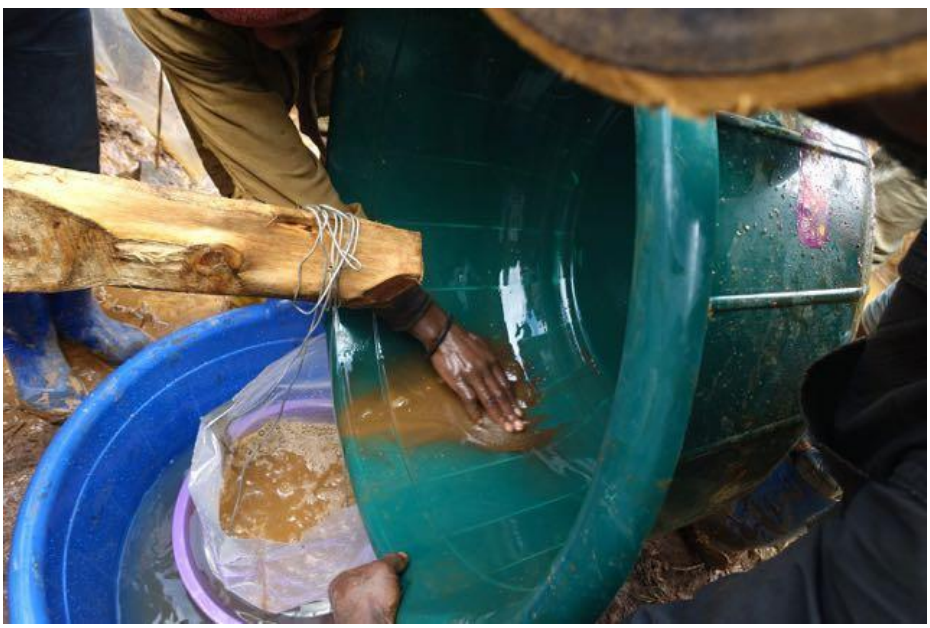

Figure 30: Emptying the last grains of sluice concentrate into the jig

Figure 31: Jig bed is suspended on the end of the boom by bailing wire strung through holes drilled in the rim of the sieve's plastic casing and in the wooden balance.

3.0 RESULTS

The experiments conducted yielded highly variable results due to the diverse quality of ore used. The great variability in yields highlights two key points. First, in general ore can be extremely rich, for example 70+ grams per ton represents a very high gold concentration. Second, the ore tested on site yielded an average of 22 grams per ton. It must be noted that yield is always lower than an ore's grade, which gives the total gold content of the ore, because chemical-free methods can only recover a portion of the gold in primary ore.

The team found no significant amounts of gold in the tailings from any of the experiments, indicating that the methods used were sufficiently effective in terms of gold recovery. The most meaningful results came on the second day when the team processed tailings that had already been processed twice. Despite the tailings being fed to the Z sluice without re-grinding, they produced more than 2 grams per ton of material. (This caused quite a sensation among onlookers, and greatly increased interest and confidence in the Z sluice method.)

Figure 32: Portable aluminum sluice test

Workers were paid to pan out the material in the tailings catch basin (red) to ensure the method did not lose any coarse gold.

TABLE 1: SUMMARY OF RESULTS

Method; Quantity	Aluminum Sluice; Primary Ore	Z Sluice; Tailings	Z Sluice*; Primary Ore	Z Sluice/Jig; Primary Ore
Date	Nov. 8	Nov. 9	Nov. 10	Nov. 11
Mass (kg)	14	42	14	27
Gold (g)	1.0	0.1	0.1	0.9
Yield	**72.4**	**2.4**	**7.1**	**33.3**

*The November 10 sterile ore sluice/jig test is not included because it yielded no gold.

3.1 SIEVE TEST

The team sieved raw material just as it was when it came out of the mine. In order to facilitate rapid sieving (as there was no time for drying), the group sieved the raw material wet. Due to the moisture, it was impossible to estimate weight, so weights are approximate. The team poured off all excess water, which led to material losses because the finest suspended sediment (such as mud and clay) ran off with the water. Table 2 presents the size distribution of particles in the raw ore that arrived at the processing station. Almost 20 percent of the material was smaller than 1 millimeter, and much of this could be concentrated directly to capture free nuggets and gold dust that might already be liberated. Not only did this save the effort of grinding 20 percent of the material, but it also improved gold recovery, as less gold was pulverized.

Figure 33: Dry sieving the raw ore sample

The sieved fractions could not be measured precisely because the ore was never dried.

TABLE 2: RAW ORE SIEVING RESULTS

Tyler Sieve #	Particle Size (mm)	Mass (kg)	Mass (%)
2	10	4	29.0
-2	-10	6.6	47.8
-12	-1.68	0.879	6.4
-20	-0.841	1.41567	10.3
-50	-0.297	0.56734	4.1

Figure 34: Wet sieving the raw ore sample

3.2 KEENE PORTABLE SLUICE

The team sieved fractions finer than 20 mesh on the Keene portable sluice, starting with the finest and moving up to the coarsest fractions. The group placed the sluice directly under the artesian well outlet, so the water was forceful and voluminous—probably too much so. The purpose of this test was to try a sluicing method that would present the least deviation from current methods and the least amount of additional labor. Adding the flow regulator, as done in subsequent experiments, could improve the water flow and consequently the recovery of the portable sluice. Panning the first sluice concentrate yielded 0.4 gram of gold. The team then crushed the ore and recovered an additional 0.6 gram from sluicing the crushed material. Given that the original mass of ore was 13.8 kilograms, the overall yield of the ore processed using this method was 72 g/T, indicating very rich ore (see Table 4). The yield from the material separated, instead of milling all the material together, was 172 g/T.

Figure 35: Concentrate formed from jigging the sluice contents

Figure 36: About 0.1 gram of gold obtained in the jig concentrate of the 14-kilogram ore sample from Day 1

The team also used the Keene portable sluice for the second sluicing event; however, they used the same washing station as for their usual blocked culvert washing method. The water flow was not strong enough, and the material sedimented quite quickly. This likely led to increased losses and a lower concentration ratio. In the future, the Keene sluices should be used with the flow-regulating water box (as for the Z sluice on Day 2). The team sold the cumulative gold (1 gram) to the negociant, who paid about $US10 for it (about one-third of the international price).

Figure 37: Second trial of the portable sluice, using the traditional washing station and wash water flow

TABLE 3: PORTABLE SLUICE TEST ON -20 MESH FRACTIONS OF RAW ORE

Material	Mass
-20 raw ore	2,326 g
Concentrate	893 g
Tailings	1,434 g
Gold	1 g
Yield	**172 g/T**

TABLE 4: PORTABLE SLUICE RESULTS FOR RAW -20 AND GROUND ORE

Material	Ore mass (g)	Gold (g)	Yield (g/T)
Raw ore -20/sluice	2.3	0.4	172.0
Ground ore/sluice	11.5	0.6	52.3
Total	**13.8**	**1.0**	**72.4**

3.3 Z SLUICE

On Day 2, the team trained four miners and project staff to build and assemble the Z sluice to process tailings. Once again, a large crowd was present. The material being processed had already been processed twice: once as primary ore and once as ground and reprocessed tailings. Consequently, no one expected to recover significant gold. Yet, the group obtained 0.1 gram of gold from a 42-kilogram sack of tailings. Since the tailings were fine and wet, the yield is approximate, and is likely higher than the calculated value because as much as 5 percent of the weight was water. The crowd of miners were very surprised to see the amount of gold in the shovel at the end of the process. This in turn created excitement and an enthusiastic response for the double-decker Z sluice.

Figure 38: Another big crowd gathering for the jig test

The group purchased and milled ore for the next day; however, when the field team arrived at the site, they determined the ore to be sterile material. Like all the ore being processed, this selection had significant amounts of pyrite in it. As pyrite is a useful proxy for gold, the group tested the jig for pyrite concentration power.

The chef du puit supplied about 14 kilograms of ore that was anticipated to be of high grade. The group ground up the ore while the first batch was being processed, and the team then processed the new batch on the Z sluice. The second sack of ore for the day yielded a significant amount of gold (0.1 gram) for such a small batch.

On the final day, the chef du puit provided ore to the team who then crushed and ground it in the traditional manner before processing it with the sluice and jig. Only concentrate from the upper sluice length was concentrated with the jig. Using the green carpets, the team cleaned the second sluice length separately and panned the contents to ascertain the proportion of gold captured there. The group did not capture any measurable amounts of gold from the second stage of the sluice, likely because the total amount of ore was small. Insufficient material was being processed to saturate the upper sluice carpet with concentrate.

Finally, the team sieved and re-ground all of the tailings to +20 fraction of the material. Panning this material yielded visible gold, but not enough to be measured. Bulk re-grinding of ore could be profitable if done in a sufficiently automated and scaled-up manner.

3.4 JIG

While workers concentrated on the sterile material on Day 3, the team trained four miners and project staff to build and operate the jig. The group added the sluice concentrate to the jig. The team showed the large crowd that had gathered how the jig operated, beginning with short (10–30 cm) and quick (1 second) lifts of the jig pan that were let to freefall into the concentrate basin. One of the miner helpers began to operate the jig, for a total jigging time of 20 minutes. Following this, the group panned both the jig concentrate and tailings to assess the relative concentration efficiency of the method. By visual estimation, this method captured about 90 percent of the gold and pyrite in the concentrate, while about 25 percent of the sluice concentrate passed into the jig concentrate. While the gold and pyrite recovery was relatively good, the mass reduction was not significant enough to warrant the extra equipment and time needed for this method. In the future, it would be better to sieve the sluice concentrate and only use the +50 fractions in the jig. Since sluice concentrate still contained too much fine material, water flow through the ragging medium was reduced.

Figure 39: 0.9 gram of gold (seen here with some pyrite crystals still mixed in), still wet on the shovel in which final concentration was done

Figure 40: 0.9 gram of ore, dried out on the shovel in which it was panned out of the concentrate

Figure 41: Testing the Estwing gold pan for concentrating the sluice concentrate

During the final day's test, the jig concentrate was about half the mass of the original material although 50 percent mass reduction is not optimal. Fortunately, the team captured a higher proportion of gold in that concentrate than in the first jig test (0.7 out of 0.9 gram of gold collected in the jig concentrate versus 0.6 out of 1.0 gram of gold in the previous day's jig test). This second result is illustrative of a common principle in mineral processing: the lower the concentrate mass, the lower the gold capture efficiency. Therefore, having a lower concentration ratio—the proportion of original material mass to concentrate mass—results in fewer losses, but creates a larger amount of concentrate to be processed.

The lower recovery rates in the final day's jig test may have been due to the operator being given more latitude in the process (i.e., regarding the height and frequency of the lift/drop motion). During this test, the operator made more exaggerated motions, letting the jig bed rise up higher and fall farther down each time. As a result, there were more splashing and lower concentration efficiency, both in terms of the percentage reduction of mass in the concentrate versus the original input and in terms of the proportion of gold captured in the jig concentrate.

Figure 42: Panning the jig concentrate and tailings separately to assess the concentration efficiency of the device

Figure 43: Clean ragging bed material ready to be reused

3.5 MERCURY USE AND THE NEGOCIANT

The Nyamurhale mine site is currently mercury free. This is due in large part to the skills of the negociant. He spends all day waiting for the miners to bring him tiny amounts of gold (perhaps as little as 0.1 gram). One trial produced just under 0.1 gram, or a bit less than the weight of a match head, and the miner was told to come back with double. Only then would the negociant buy it. During the testing, he made relatively few sales, perhaps obtaining at 5 to 10 grams during a typical day, although this cannot be confirmed. The negociant had a keen eye and displayed immense patience. Because of the meticulous care of the negociant, miners do not need to use mercury and it has been noted that miners have decided not to use it. Use of mercury could prove to be easier and may produce more gold than the methods currently used. It is important, however, to be proactive in helping miners improve their gold recovery without the use of mercury. Therefore, if mercury were to be introduced, it would have a higher standard against which to compete.

Figure 44: Typical gold recovery for one sack of ore

4.0 CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS

The sluice tests were successful, and dozens of miners attended the demonstrations each day. Sluices were shown to capture all of the gravity-recoverable gold in each sample effectively. The tailings were panned in each case and no residual gold was found. In one case, more than 2 grams per ton (g/T) of tailings material were recovered using the Z sluice. This impressed the miners, because as the ore waste had been processed twice, they had not expected it to yield any more gold. This indicates that current methods are wasteful and reprocessing tailings is worthwhile, despite being time consuming. If that same amount of overall labor were applied to processing the ore more efficiently the first time, the overall efficiency of that labor would be increased and more ore could be processed for greater profit. The current system is inefficient in terms of labor, but distributes wealth to lower socioeconomic ranks (re-processors are often lower-income residents without access to primary ore).

Ultimately, the labor applied to processing primary ore is insufficient and inefficient, because the processors have no incentive to work more carefully and judiciously. Since they are paid by the sack, they have no stake in the profits that would accrue. If the cooperative were to take control of the gold buying, provide better processing tools, and pay/supervise ore processing laborers, it could potentially preserve or increase jobs on site while increasing gold recovery.

Mercury is not used in the Nyamurhale Mine site; however, that may change. Improving chemical-free gold recovery could help to ensure that mercury is not seen as a viable alternative. It may be worth considering having an entity pay the miners for their gold and collect it for smelting, because the miners already concentrate the gold enough to allow efficient melting. Gold ingots are easier to analyze for purity and sell for a higher price. Ideally, the cooperative itself would become the site gold buyer and smelter; however, the negociant would not be cut out completely, as the gold can still be sold into the same supply chain. Ultimately, the best approach would be to export the gold directly so miners get the highest possible price.

4.2 NEXT STEPS

Multi-element analysis of ore from the site

Only enough ore was available each day to meet processing training needs, so CBRMT staff were instructed to purchase fresh primary ore directly from the pit boss and to pay a decent price for it.[1] This sample will be shipped to an SGS laboratory, with labs in Kinshasa, Mwanza, and nearby.

4.3 BARRIERS TO AND SOLUTIONS FOR INCREASING UPTAKE OF NEW METHODS

Ultimately, techniques demonstrated at the mine site for this assignment take more labor and time than the current methods being used, and the increased recovery may be insufficient to stimulate people to exert extra effort.

The Z-sluice had to be stored and returned to the place of use each day, along with the catch basins. In addition, fresh water had to be supplied from the source. To facilitate adoption of the sluice, initial steps

[1] Cordy Geosciences will reimburse the field staff for this cost since this was part of the present contract.

required would include installing it permanently to ensure proper slope of the decks. A clinometer (or clinometer smartphone app) can assist in ensuring that the sluice slopes have the optimal inclination, with a slightly steeper first stage. The sluice should also be placed where it discharges directly into a pond, as the tailings catch basins were used only to help assess the efficiency of the sluice methods.

Operationally, the miners are unlikely to save tailings because those in control of ponds and mineral waste may object to people removing the tailings. The tailings are a potential resource, and their ownership needs to be clarified. During the site visit, it was not known whether the tailings were excavated and sold or only reprocessed locally. Ultimately, the tailings need to be moved from the mine site so the washing pits as Pyrites produce acids as they oxidize, and these can leach other heavy metals into groundwater.

The bucket water supply method is the biggest work barrier to the adoption of sluices. It is tedious, laborious work that could be made much easier with a hand pump. The Clinton Global Initiative sells manual pumps throughout Africa that would be ideal for this purpose. However, these were not available in either Bukavu or Canada. Another labor-intensive aspect of operating the Z sluice is mixing the ore slurry by hand—although this is not more work that the loutra method. Miners did request a larger ore-mixing box to allow for larger loads of ore. Finally, unloading the sluice and cleaning the carpets are time consuming as they leave a relatively large mass of concentrate to be panned in a wash basin using a shovel. Although these steps are also used in the loutra method, the basin panning step might take longer because more concentrate will likely be generated by Z-sluicing.

Figure 45: Cleaning the sluice carpets

Contemplating the use of a new method to increase gold recovery in this community highlights the fact that processors have no stake in the quality of their work. Miners will always have more material to process, regardless of the efficiencies achieved. Replacing their primitive methods with the advances described in this report will see significant gold recovery, but this may not be enough to achieve impact at the individual scale. Reviewing the entire site's daily or weekly production from a single pit could help to demonstrate that the additional gold obtained is worth the extra effort. For an individual trial, any extra or lesser amounts of gold could be explained away as due to the natural variability in the ore grade. Furthermore, each particular recommendation for improving efficiency would only improve recovery by a few percent. It is when improvement is made in multiple areas along the processing chain that 15-or-30-percent increases in production can be achieved.

A well-planned test reorganization of the site should be considered. This would include preparation of the community ahead of time, to include contracting labor and renovating inefficiencies (such as ore selection, crushing and grinding, concentration, and direct smelting). This test should be run parallel with the business-as-usual case for a week, while carefully measuring the amount of ore going into each process and the gold going out. This would allow people to observe a concrete profit difference and demonstrate whether the extra labor cost is equal or greater than the additional income.

Ultimately, some mechanization will be required to increase uptake of better methods. As it stands, not enough labor is devoted to ore processing, which leads to an insufficient value being placed on it. Therefore, increasing the productivity of processors by relieving them of grinding by hand would free them to do more interesting, varied, and technical work such as sieving and feeding. This would provide a more concrete symbol of progress when compared to traditional mortar and pestle systems. The site as a whole could be wealthier if the parties pooled their ore and processed it all together. To achieve this, the cooperative must exert control over the ore supply, processing, gold sales, and payment of services.

4.4 ORE PROCESSING IMPROVEMENTS

This section is intended to inform the procurement of equipment to improve production, processing, and efficiency of the existing technologies in the supply chain process. It also provides additional options on how to improve production throughout the artisanal mining life cycle (such as solutions for mining, washing, and treatment). Solutions are given in order of the processing chain, with milling solutions arranged in order of increasing complexity.

Options are presented for mechanization or using only manual power. Either way, the basic goals remain: size classification, optimal grinding, careful concentration, and direct smelting. Mechanization is not necessary to improve all aspects of ore processing; however, best practices require more effort and might therefore be more likely to be adopted if there is a labor-saving element to them.

In practical terms, procuring ready-made best practices for ore processing equipment in the DRC may be difficult. The recommendations here focus on equipment that can be built by local carpenters and welders out of readily available materials in Bukavu. Two change scenarios are described using the tools previously explained or diagrammed in this report: mechanized and non-mechanized. Both approaches use the same quality control protocols described herein.

The non-mechanized approach:

- Hand-crank trommel
- Mortar and pestle or hand-crank ball/river stone mill
- Manual shaker screen
- Barrel collectors
- Z sluice

The mechanized approach:

- Motorized trommel
- Water pumps and hoses
- Mechanically driven ball/river stone mill (ideally with a mechanical crusher feeding it)
- Z sluice
- Shaker table
- Generator

Equipment is available for import from other countries. The Artisanal Gold Council purchased a Chinese-made wheel mill and shaker table, smelting torches, and crucibles for its projects in Burkina Faso and Senegal. However, the equipment alone cost between $US40,000 and $US50,000. This setup would work well in the Nyamurhale Mine, but it would be important to find a good manufacturer to ensure products do not break down quickly or function poorly. Buying equipment from a company such as Mount Baker Mining and Metals (MBMM) should also be considered. They import equipment from China (where iron and casting is cheap) and upgrade welds, reinforce wear points, and swap in higher-quality bearings. They also make the best shaker table on the market, using the Diester design, with high-quality springs steel and highly resistant surfacing material. All parts are manufactured in the United States. The MBMM table can produce gold concentrates that are of a grade high enough to smelt directly, with a cost of approximately US$13,000.

The Tanzanian mill is commonly used in East Africa and even in Ituri, DRC, but it is not recommended. It is loud, inefficient, produces a great deal of dust, and is quite costly for a machine of such low quality. It would be better to fabricate a mill in Bukavu and build a new local industry around it if the test proves profitable. For short-term milling needs, such as training or running an experiment to evaluate the effectiveness of a ball mill on site, a cement mixer with the mixing blades removed is an effective and widely available substitute for a mill. Mixers are made of highly durable steel and have variable speeds. Simply adding ore, water, and steel balls or round river stones in the correct proportions could result in milling of hundreds of tons of ore before the drum wears out (new drums are not too costly). Cement mixers are available in Kigali and can be ordered ahead of time.

The mechanization approach would process ore faster and increase labor needs while vastly increasing productivity. Miners could process more ore in a shorter amount of time, which might make it worthwhile to process lower-grade material. At present, miners only process very high-grade material and achieve poor recoveries. If the proportion of the mined material that could be processed profitably were to be expanded while also improving the amount of gold produced from each sack of ore processed, significant improvements in livelihoods would be evident at the site.

4.4.1 NEW ORE-PROCESSING TOOLS

Washing Trommel. Trommels are sloped, irrigated, spinning cylinders with holes in the lower third that wash sand and clay from the ore. A trommel could be made out of a 5-gallon paint bucket or a large propane tank, supported by shopping cart wheels and spun by a hand crank. A pump feeds water into a PVC pipe inserted off center in the downward moving side of the cylinder, with holes that spray water across the cylinder into the lower quadrant of the tube. This stacks and tumbles the ore to wash it clean of smaller material. Below the perforated lower third of the cylinder, plastic sheeting (or a halved barrel) catches the finer material and feeds it onto a sluice to concentrate the gold that is already liberated. The cleaned oversize material then drops out of the lower end of the cylinder into a basin where it is then crushed and ground. This trommel will be described in more detail in a second report.

Rock Chip Catcher Ring. This tool is useful for breaking up rocks less than 10 cm in diameter. This tool can be constructed by twisting a rice sack into a long cylinder and coiling it into a two rings with a ~10-cm-wide hole in the middle and a handle on one side. The two rings are then tied together with string or plant fiber. With rocks placed inside the ring, a hand-sized sledgehammer (2 to 4 pounds) can be used to smash them. For larger pieces, a sledgehammer can be used to reduce the size to 10 cm.

Figure 46: Women in Kenya using a rice sack rock chip catcher

Half-Barrel Hopper. Currently, mine site workers discharge material into a tarp with holes in it, which leads to further losses of some of the primary material. A half-barrel hopper can be made from a steel or plastic barrel cut in half (available in Bukavu or Kigali), with the open end pinched underneath the grinding rock pestle so that the closed end catches material that rolls down, could be used instead. Holes should be drilled in the lateral edges of the barrel and ropes tied into them to make handles for easier movement between stations. Enough barrels should be made to supply at least one to each process station to enable easy feeding of the crushed or ground material onto the screen. Periodically, barrels should be emptied onto a screen and the oversized material be returned to the same processing station for re-crushing or re-grinding. These should be made of ~1 mm window screen material, which is readily available in Bukavu. Given the fine grain of the gold at this site, it may be necessary to use the same equipment to regrind the >1 mm material and sieve it with a finer mesh screen (also available in Bukavu). It is highly recommended that fractions smaller than 1 mm be sluiced before re-grinding.

Rocker Screen. Screens can be made using two layers of rectangular wooden frames with the screen sandwiched between them and the screen stapled to the upper frame. The long sides of the wood frame should extend beyond the screen and be shaped to make handles, so that the frame can be shaken back and forth to facilitate sieving. It might be useful to build a larger rectangular support frame with legs, from which the screen frame can be hung using triple-layer rubber straps at the four corners. This will make a swinging screen that can be operated by a single person.

Metal Mortar and Pestle. To make a metal mortar and pestle, cut and weld a vertical, round-bottom metal cylinder with an open top and a base ring for stability. After welding, a 4-pound sledgehammer head could be lashed to a straight stick of similar diameter, making a mortar and pestle of the same form as is commonly used to locally make flour. The pestle could be made out of a tall propane tank. Commonly used local tanks supply propane to the Orchid Hotel kitchen in Bukavu (~25cm diameter and 1.5m tall). Before welding and cutting the propane tank, it should be laid flat and filled with water to prevent an explosion. Once the top end has been cut, it should be filled with wax or stuffed with twisted banana leaves or rice sacks. This will help hold the water when the cylinder is rolled over to continue the cut on the bottom side of the flat-lying cylinder. It may be efficient to weld a frame and stand, as well as metal axes on the sides of the cylinder near the edge of the cut, so that the cylinder hangs vertically and can be easily tipped into the half-barrel hopper. The ore can then be milled in an approach similar to milling flour, i.e., periodically emptying the pestle onto a screen and returning the oversized material into the pestle for regrinding. Screens should be used as described above.

Hand-Crank or Bicycle-Powered Propane Tank Ball Mill. A large propane tank with thick walls can be used to construct an excellent ball mill if mounted on a rotating axis with spin bearings and a hand crank or drive mechanism. A door cut into the tank allows for the ore, water, and grinding medium to be fed and discharged. Steel balls about 2 to 3 inches in diameter, or carefully selected round river stones, act as a grinding medium. The drum is then turned at about 70 percent of the speed at which the grinding medium is pinned to the walls by the centripetal force. The grinding medium should cascade inside the mill, lifting up and then falling toward the center of the drum and impacting the ore inside.

Sparse Application of Detergent. Use of soap will help prevent floatation losses of fine gold by cutting the greasy film that often coats gold particles, thereby allowing them to settle. Pure detergents, when sparingly applied, can cut grease without producing too much foam (which can recruit fine sulfide and gold particles, thereby negating the grease-cutting advantages). Jet Dry dishwasher rinse is optimal; however, that brand not be available locally.

Figure 47: The Z sluice, ready for testing

Detergent helps cut the grease on smaller laminar gold particles that could otherwise wash away. Only small amounts are used to avoid foaming that could float the fine gold.

V-loutra. V-shaped loutras trap heavier minerals in the bottom of their troughs better than in the semicircular ones, thereby leading to higher concentration of gold particles and fewer losses. These can be made from the same metal half pipe hammered flat and then hammered into a sharp angle over another metal edge.

Shaker Tables. Shaker tables are slightly inclined tables that shake along the long axis, with troughs above also aligned in this direction and water flowing across them. Ore is loaded onto the table at the top edge. Heavier minerals are trapped in the troughs, which are then conveyed along the table to the collectors at the far end. At the same time, lighter minerals flow with the water into the tailings collector. These relatively low-power tables are simple to set up and operate. Ore can be re-fed to the table in order to upgrade gold concentrations enough to allow for direct smelting.

4.5 THE NEGOCIANT, MERCURY, AND REFORMING THE GOLD BUYING CHAIN

Miners working in the Nyamurhale Mine site do not use mercury, even though using it could make work easier and produce more gold than the methods currently used. Process improvements should be proactive to help the miners improve their chemical-free gold recovery. If miners decide to experiment with mercury in the future, chemical-free processes will have to compete against mercury. Gravimetric methods (such as sluices, jigs, and shaker tables) can produce amounts of gold equal or greater to those recoverable with mercury, although the methods may use more capital or be more labor intensive. If the cooperative had greater control over the gold trade on site, it could leverage the extra income to provide and maintain better tools. The negociant, and his meticulous grain-by-grain gold-buying methods, may be the primary reason that the site continues without the use of mercury. If the process is to be changed to favor of the cooperative, it must be done so without disrupting the negociant's role. Ultimately, it may be advantageous to cut out all of the middlemen and export the gold directly to maximize value at the site. However, that may not be possible or desirable for reasons that are beyond the scope of this report.

The miners are not sensitive to losses as long as they get enough material to meet their daily needs. Occasionally, a middleman buys gold on visual speculation and then sells it to the negociant located nearby for more than double the price. If the cooperative could become that middleman and all the members of the cooperative benefitted from greater revenue, then it could help reorganize the site economy and restructure it for greater efficiency of gold production and an increase in skilled labor.

Ideally, the cooperative would be the entity that pays miners for their gold immediately. The cooperative could then pool the gold concentrates so that they could be smelted when they have collected at least 10 grams of gold.[2] The cooperative could then sell its gold to the negociant. If the cooperative received the raw gold concentrate instead of giving it to the negociant to separate out the grains of nonmetallic minerals, it could melt it into an ingot. This step would eliminate work and waiting for individual miners. It is likely that the negociant would be agreeable with such an arrangement; however, after miners have smelted ingots of gold, it could be more efficient to sell directly to the exporter.

[2] Ten grams is the minimum amount of gold that one can melt without risking losses. These losses are not permanent, as the slag (black glass that forms on top of the gold ingot during smelting) contains the lost gold. This lost gold can be recovered by grinding the slag with the raw ore.

Figure 48: Worker pleased with the final day's gold recovery using the sluice and jig

4.6 PURITY

Each ingot of gold has uniform purity; the size or combinations of original ore do not make a difference because the purity is homogenized during melting. To determine the purity of an ingot, a tiny shaving of gold from the ingot can be drilled out (using a small metal drill bit) and analyzed by a spectrometer. This could be done at a laboratory such as SGS in Kinshasa or through desktop analyzers. Based on precise purity, an accurate price can be assigned. Knowing the gold purity from each of the different types of ore being used makes it possible to track how much gold went into an ingot. Because tracking ore types of each ingot is not easy, it is best to have an in-house method for analyzing purity. Another option would be to melt several bars into a single larger one and conduct one analysis for all of them. Of course, the miners sell the gold obtained from a single pit each day. Therefore, by knowing the average purity for the type of ore extracted, they should be able to assert their gold's purity without having to analyze it each time (impractical for the tiny amounts that each miner produces daily).

The simplest way to measure purity of an ingot of gold is to use an analytical balance to weigh the gold in air and underwater,[3] and then use a table to look up the purity value of the gold. This method is commonly used in gold shops to assess purity and determine a purchasing price. Gold-buying shops in Bukavu use this approach.

In addition to the aforementioned methods, special instruments are used to test gold purity, such as X-ray fluorescence spectrometers.[4]

4.7 REORGANIZING LABOR FOR EFFICIENCY AND EQUITABILITY

CBRMT staff expressed concern about introducing labor-saving technologies to the site. They wanted to make sure that new solutions would not decrease the amount of labor needed and eliminate income. Of more concern is the fact that not enough labor is being applied on site (and the labor applied is inefficient) to process minerals. Ore processed by hand, by grinding, size separation, and concentration, results in labor costs that are two to four times higher. Therefore, the addition of more efficient, motorized, high-capacity equipment would only change the skill level of the labor involved, and may even increase labor needs on site because of the need for several new skills. This increased efficiency could consequently increase cash flow to the site.

Unfortunately, efficiency and low price do not appear to concern the miners. During the site visit, one miner accepted only a third of the value of his gold from the negociant. This could work against efforts to increase efficiency, especially if these efforts result in increased labor or capital costs. However, efficiencies would help the cooperative achieve greater control of income flow because miners might not mind receiving a low spot price if they did not have to wait for the negociant to pick out the pyrite. They may also see the benefit of having a cooperative to manage and pay miners for their labor, as well as manage the site's income. It has yet to be determined whether the miners trust the cooperative enough to enact this change. It is essential to try and foster trust, as efficiencies require pooling of capital, efforts, and recovered gold. It will also be critical to create a system where the miners cannot or will not attempt to steal the gold during final concentrate, as they might be able to do so with a shaker table or during smelting, when the gold becomes visible.

4.8 TAILINGS MANAGEMENT

At present, there is no control over suspended sediment. At the Nyamurhale Mine site, a series of settling pools is present, where people loutra or sluice ore, but there are no organized, series-linked ponds that progressively settle out the finest sediments. A set of concrete ponds could be constructed below the town/washing site where gold can be recovered. Inevitably, the finest suspended sediment will still be lost. Therefore, it would be advisable to investigate where the effluent goes and how the water levels vary in the creek or river into which sediment discharges.

Most material collects in the first washing pond, which is emptied and reprocessed from time to time. The ultimate disposition of all tailings should be investigated and a plan developed for their proper containment. In principle, the site would have a large pit lined with a geomembrane that could accommodate at least a decade's worth of tailings. Alternatively, the tailings could be sold to another gold processing facility, such as Banro. Because more than 2 grams per ton of gold were recovered from twice-processed waste during this study, there is a strong economic argument for the reprocessing of

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[3] See The Uses of Below Balance Weighing (https://www.adamequipment.com/what-is-below-balance-weighing-used-for) or Gold Tester (http://www.worldoftest.com/gold-tester-gold-platinum) for examples.

[4] http://alloytester.com/xrf-gold-tester

the tailings with cyanide. Commonly, gravity concentration methods recover less than half of the available gold in ore. Given the average chemical-free yield of 22 grams of gold per ton, the tailings of that ore likely contain profitable residual gold concentrations, even if processed with best practice gravimetric methods (sluices, loutras, shaker table, etc.).

4.9 ORE EXTRACTION

To improve ore extraction, stability assessments and better timbering for the underground shafts are necessary. There may be sections where the rock is hard enough that additional timbers are not necessary, but these sections are likely deep and few. Shaft depths are limited by the water table, fresh air, and the number of open pits that are producing. Improving ventilation with fans and ducting would be prudent. In addition, pumping out the groundwater could improve the regularity of production in the wet months. Honda waste pumps with are generally available in major centers such as Kigali. These waste pumps are designed to handle sands and mixed slurries, making them less likely to break down.

Because so many pits are in such proximity to each other at the Nyamurhale site, a large stepped excavation face on the hillside should be considered. Although this step could require a significant amount of labor, the overall efficiency of the labor could be greater if it were made more efficient and safe. A small hydraulic excavator could make the excavation proceed relatively quickly and could expose a great deal of material to be sorted and picked over. A system should be developed for transporting and dumping ore. A terrace design would save time in moving ore up and remove the danger of underground collapse. Slope stability would also have to be evaluated to ensure the safety of open workings, but monitoring and evacuation are much simpler in the open-pit model. If trenching uncovers more veins, a road could be constructed across the low side of the slope where most of the pits are located, to wheel out ore and waste in carts. Rather than searching for high-grade ore in tiny pits, the best ore could be selected for processing (i.e., various kinds and grades of ore in stratigraphic order). Surface oxides may be lower in grade, and the workers would have to work more systematically (instead of digging straight down to the richest part of the vein). Exploration could also provide information to verify that the gold yield per unit of labor will sustain the community through the beginning, middle, and end of this propitious deposit. More importantly, such an assessment can be constantly updated with production data.

A study should be conducted of the exact location of each pit and its productivity history, including the number of bags produced per day, the length of time the pit has been active, and grade and purity change over time. The study should also include the shafts' current depths and structures (e.g., straight down or with branching, horizontal galleries). All this information could be used to generate a rough map of the subsurface and its properties, including the orientation, nature, and extent of existing veins. Mapping these features could facilitate exploration target choices and tunneling strategies. Assembling these data would be the first step in developing an exploration plan to define the area's resources as best as possible.

4.10 EXPLORATION

The first step in any exploration program is to acquire all the highest-resolution local geological information possible, such as geologic maps produced by the state or mining companies. A careful inquiry and search using the National Geological Survey and mining ministries may also provide important background information, possibly including historic gold exploration and mining data from the region. This step could suggest priority areas to investigate in a more detail, and would help to understand the nature of the subsurface geology. Furthermore, air or satellite photographs can capture the regional geological structure, such as faults that could have created or shifted gold veins.

Geophysical data may also be available to provide a distinctive geo-chemical distinctive signature at the mine site and nearby areas.

To determine the geochemical signature of rocks that host gold, multi-element analysis of all the local ore types is required. New exploration sample mineralogy and geochemistry can be compared to determine whether nearby areas are a close match. As experienced miners would be the best prospectors, they should be hired to carry out an artisanal exploration survey of the area using a metal detector. To perform the survey, miners walk the terrain, investigate outcroppings, pan in small creeks, and conduct artisanal field assays (crush and pan small samples in a shovel) under the guidance of an exploration geologist.

To define the contents of a deposit and identify probable targets for new pits near and around the existing mine site, the team conducts a modified grid sampling of surface material over a wide area surrounding the principal deposit.[5] The group identifies mineral types and their distribution in 1-to-2-meter-deep pits and collects material for analysis in a laboratory. A typical high-resolution sampling grid would test 25-meter pits spaced 50 meters apart. The exploration could also include nearby hills with outcroppings and pit sampling. The cost of laboratory analysis of the samples gathered is estimated to be US$30 per sample; however, US$20 per sample is likely for bulk processing. Sampling a 2-square-kilometer area with an 80x40 grid would cost almost US$50,000; however, the sampling density could be cut in half and still provide sufficient initial detail.

Trenching beyond the existing mine in a direction perpendicular to the orientation of the gold veins could uncover other possibly richer veins and extend the life of the mine. It could also be used to assess other mining methods that might be safer or more efficient, such as open-pit or terrace mining.

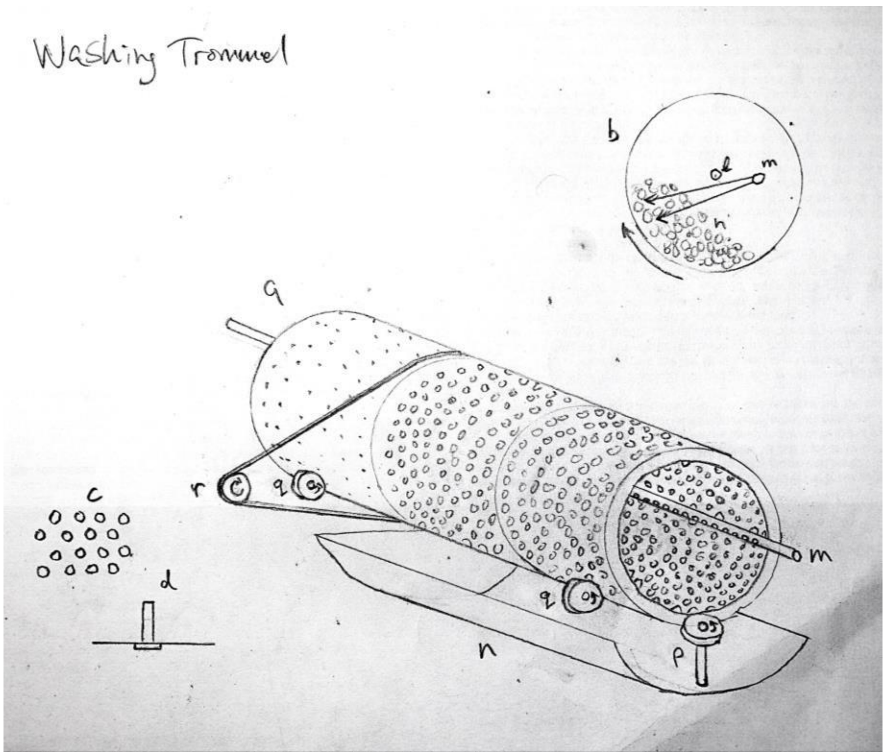
Soil sampling, geologic mapping/research, and trenching all reveal surface anomalies that should be assessed by drilling. There are some artisanal options for drilling (http://www.backpackdrill.com/, http://www.minex-intl.com/winkie-drill.php) which would need to be done under supervision of a geologist who would then target and monitor the progress into the best targets.

5 A modified grid is neither regular nor entirely random, but designed to sample an area thoroughly through informed site selection.

5.0 EQUIPMENT SCHEMATICS

The descriptions below highlight the main elements of some of the tools referenced in previous sections, and provide design schematics. The size of the tool and construction materials can vary depending on what is available and the desired capacity (e.g., trommels can be made from discarded propane tanks or plastic 5-gallon pails). These designs provide general principles and key parameters and proportions. Some sketches include a rough scale, but they will work at larger scales with the same relative proportions.

5.1 WASHING TROMMEL



Schematics

a. Washing trommel main view. Note that the lower two-thirds of the tube have holes drilled as per schematic "c." The cylinder should slope about 10 degrees.

b. End view of washing trommel showing positions of center axis, spray bar, and ore.

c. The holes must be separated from each other by one hole width and be offset by one hole width, so that sand missing one hole will always fall out of the next row of holes.

d. In the upper third of the trommel cylinder, bolts are attached so that the bolt threads protrude into the cylinder between 5 and 10 centimeters.

Elements

m. Central axis of the trommel (may or may not actually be a physical bar here).

n. Spray bar. A PVC pipe with holes sprays pressurized water at the ore as it tumbles inside the trommel. The spray bar must be located so it does not hit the central axis.

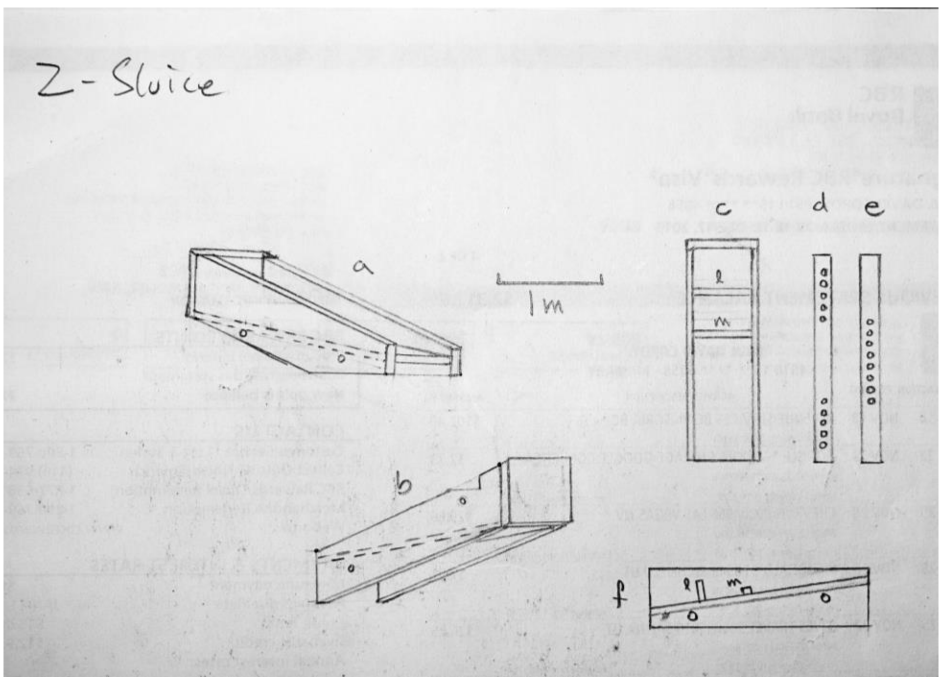
o. Ore tumbling inside the trommel will bunch up in the lower left quadrant of the trommel if the rotation is clockwise. It is critical that the spray bar be pointed at this area to maximize washing effect.

p. A wheel at the end holds the trommel in place, and a rim on the trommel end gives it a place to push against and retains the slurry so that it does not discharge with the coarse waste.

q. Wheels with sealed bearings keep the trommel in place and rolling smoothly. These could be shopping cart wheels or an Isuzu drive differential and tires; the differential would spin the trommel and is more appropriate for a large trommel made from a large discarded propane tank.

r. Drive mechanism and belt system to turn the trommel. This could be powered by a hand crank, bicycle, or motor.

5.2 Z-SLUICE



Schematics

a. Top sluice deck main view.

b. Bottom sluice deck main view.

c. Sluice deck top view (elements l and m are only built into the top sluice deck).

d. Leg design for the load/discharge end of the sluice. The holes allow for bolting to the decks to achieve different inclinations.

e. Leg design for the other end of the sluice. The holes allow for bolting to the decks to achieve different inclinations.

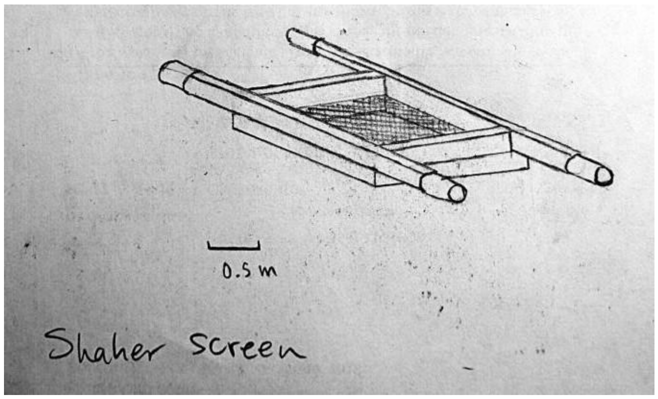
f. Side view of top sluice deck.

Elements

l. A higher barrier in the top sluice deck creates a reservoir for the flow-regulated water so that it spills uniformly into the slurry mixing box.

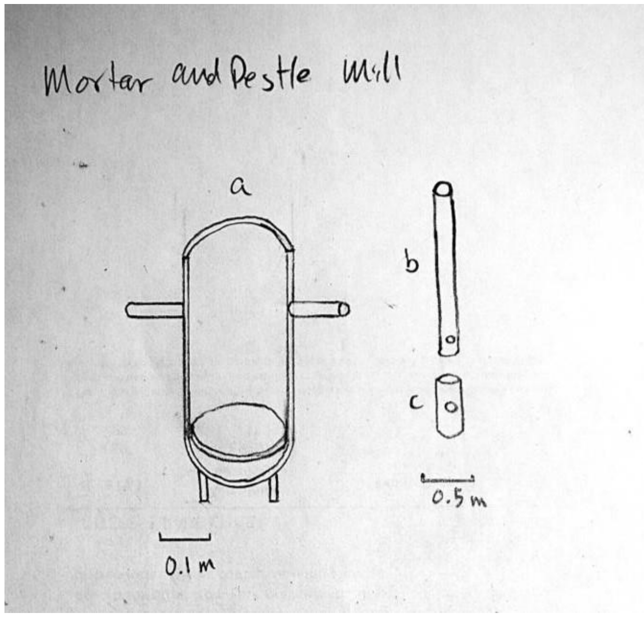
m. A lower barrier creates a space to manually mix in the ore slurry.

5.3 ROCKER SCREEN



The rocker screen consists of two rectangular frames nailed together with a metal mosquito mesh sandwiched in between. The screen is wrapped around one of the frames and stapled in place to ensure there are no holes through which larger material can pass. The upper frame has handles so that two people can rock the device back and forth while others feed the screen ore and spray it down with water. This should be coupled with a good half-barrel hopper and a tarp to catch the sieved material that spills over, as well as a separate tarp on which to put the oversized material.

5.4 METAL MORTAR AND PESTLE



Schematics

a. Mortar main view. This can be made of a discarded gas cylinder with a false bottom welded in to make a flat surface, and rods welded to the sides for picking it up and emptying it onto the rocker screen.

b. Sledgehammer handle with a hole drilled for lashing on the head.

c. Sledgehammer head, to be lashed axially with rope, bailing wire, rubber strapping, etc.

6.0 FURTHER PROTOCOLS FOR BEST PRACTICES

6.1 ORE PREPARATION

In any mineral processing test, it is imperative to mix the sample thoroughly and split it into as many equal portions as necessary to perform all the tests. This will ensure that comparisons among the tests are done with ore of the same gold distribution and quantity. This is particularly important in gold extraction studies because gold can occur in both low concentrations and in nuggets, resulting in uneven distribution in test samples. Whether using crushed ore (i.e., chunks that average several centimeters in diameter) or milled ore (generally smaller than #35 mesh [0.5 millimeter]), it is critical to mix and divide properly and evenly.

The protocols and procedures listed below are not necessarily the best possible methods, but are based on best practices and adapted for available equipment and specific conditions at Nyamurhale. For example, ore preparation, specifically splitting large samples into smaller samples of equal weight and composition, should be done using a riffle splitter. For further studies, such as those suggested in this report, a riffle splitter would be a worthwhile purchase. For the time being, however, the tarp mixing method should give reasonably equal subsamples.

Figure 49: Milled ore drying milled in the sun

This is also how one would spread out ore for mixing a sample preparation.

ORE SAMPLE PREPARATION (HOMOGENIZATION AND DIVISION) PROTOCOL:

1. Measure the total weight of test ore. It is best to use a mass of ore that is an even multiple of the number of tests that will be done.
2. Spread the ore out evenly over the whole surface of a large tarp on the ground as shown in the photo above.
3. Lift each corner of the tarp so that the ore falls toward the middle of the tarp, forming a single pile.

4. Repeat Steps 1 and 2 three times.
5. Using a long, wide piece of wood, split the pile into two equal parts, and push them apart to create two separate piles.
6. Split and separate as many times as necessary to obtain the correct number of subsamples for the number of tests that will be conducted.
7. Sweep and shovel each split sample into a separate receptacle (bag or wash basin).
8. Repeat Steps 1 through 5 for the remaining ore sample, which will be difficult to scoop into receptacles. Evenly distribute the remains among the larger subsamples. This step is very important as gold tends to settle at the bottom of a pile when shaken; this last bit of dust could contain higher concentrations of gold.
9. Weigh each subsample and adjust the weights if necessary by redistributing small amounts of ore from heavier to lighter samples.

SIEVE TEST PROTOCOL:

1. Thoroughly wash and dry all sieves ahead of time.
2. Stack the sieves in decreasing order of mesh size.
3. Weigh the total mass of ore to be sieved. Avoid overloading the sieves if a significant amount of 50 mesh grains is present, because hand-shaking large quantities of fine grains can be quite labor intensive. Do not sieve more than 2 kilograms of fine-powdered ore/tailings, or use the wet sieve method described below.
4. Place the ore in the top sieve and shake vigorously, making sure not to shake so hard that ore spills out from between the sieves.
5. Empty each sieve into a separate, pre-weighed container and weigh the contents.
6. Add up all the weights to find out how much material was lost/stuck to the sieves during sieving.
7. Separately pan each fine sieve fraction (<20 mesh) and visually inspect coarser fractions for gold nuggets.
8. Visually estimate the amount of gold in each sieve fraction. Testers and miners (if present) should reach a consensus as to what percentage of the total gold will be held within each panned concentrate and tailings sample.
9. Take pictures of the gold in the concentrate, using a one franc coin for scale and a piece of paper. Record the date and the test number.
10. If practical, for each sieved fraction, amalgamate the gold and measure the weight of the amalgam and sponge gold that results.
11. Enter the results into an Excel sheet or database.

WET SIEVING:

If most of the ore is very fine powder, it may be difficult to separate the finest grains fully using the dry sieving approach. If this is the case, weigh the cleaned sieves before sieving, wash the ore through the sieves with water, then allow the sieves to fully dry. Finally, weigh the sieves separately and subtract each of the clean, dry sieve weights.

6.2 MILL OPTIMIZATION

As with the sluice, there several parameters that can be optimized during the milling process. Principal among these are milling time and target grain size distribution to provide optimal liberation. The liberation test (see below) determines the duration of milling that produces optimal gold liberation for ore from a mine using universally optimal milling parameters. The most effective approach is to mill in short time increments until all gold has been liberated from the ore. Ideally, all other variables would be held constant at universally optimal values. For example, the speed of a rotating drum mill should be 70 percent of the critical speed, and the grinding medium should not be too worn down and its particles should be similar in size and evenly distributed (which may differ depending on the ore type and desired grind size). The mill drum should be 40 percent full during milling. The mill load should be made up of 50 percent ore, 25 percent grinding medium, and 25 percent water (in the case of a wet mill). Wet milling is preferable because it largely eliminates dust production from milling.

Fresh grinding medium (e.g., a set of steel balls) should be used when conducting milling tests to assess maximum possible recovery under ideal conditions. Further testing using worn out grinding medium can assess the changes in production that might result from less-than-ideal conditions.
Therefore, testing should be done when a new grinding medium is brought to the site, or a set of fresh steel balls should be reserved for testing.

6.3 LIBERATION TEST AND P80

The purpose of the liberation test is to determine the optimal milling time to liberate gold fully from ore. Over-milling can produce fine gold that gets lost in the tailings. Milling in discrete time intervals and emptying the mill regularly to pan out the gold allow are recommended. Dried tailings can then be sieved to determine which screen size will allow 80 percent of the tailings to pass through it. This is known as the "P80" amount. Knowing the P80 amount for a given ore allows a user to avoid having to repeat the liberation test; the mill is stopped when the desired size is achieved.

Unfortunately, the standard large-volume dry Tanzanian mill does not permit the use of the liberation and P80 test methods due to the laboriousness of panning the entire contents of the mill and the fact that returning moist ore to a dry mill would gum it up and reduce its efficiency. A modified mill test is recommended for that situation. The standard test procedure outlined below should be used for cases when a small wet mill or mortar and pestle and significant labor are available.

STANDARD LIBERATION TEST PROCEDURE:

1. Prepare uniform samples of ore crushed to ~2cm using the ore preparation protocol.
2. Grind the ore in the mill using best practices (load mass ratio of 1:1:2 for water: grinding medium: ore) for 15 minutes, empty the mill, and pan the gold in the ore slurry.
3. Load the ore slurry back into the mill and repeat Step 2.
4. Repeat Steps 2 and 3 until panning the ore slurry produces no more gold.
5. Sieve a 2-kilogram sample of tailings according to the sieve test protocol and bag and label the rest of the sample with the milling time, date, and time.

MODIFIED LIBERATION TEST PROCEDURE:

1. Make four equal samples of crushed ore prepared using the ore preparation protocol.
2. Mill one of the samples for the shortest milling time to be tested. For example, if miners normally mill for 45 minutes, recommended test mill times of 15, 25, 35, and 45 minutes.
3. Empty the mill after the allotted time onto a large plastic sheet and homogenize, as described in Steps 2 through 4 of the sample preparation protocol.
4. Collect a 2-kilogram sample from deep in the center of the resulting ore pile.
5. Sieve the sample according to the sieve test protocol and bag and label the rest of the sample with the milling time, date, and time.
6. Repeat Steps 2 through 5 with the remaining milling times.

The result of this test should be a series of grain sizes and gold amounts by time increment. Milling times should indicate when the peak gold liberation is achieved and when significant quantities of liberated gold start to break down into fine gold. The optimal milling time is that which liberates the most gold without producing too much fine gold. The sieve test will also determine the resulting grain size distribution.

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